Science and Technology
Digitizing Information

By the end of this chapter, you should be able to:

Language of Science

? describe the three basic components of flowcharts.

? describe the three-part structure of feedback.

Patterns in Nature

? describe the results of adding red, green, and blue light.

Mathematical Tools

? convert from decimal numbers to binary code and vice versa.

? convert voltage samples to binary code.

? convert color samples to binary code.

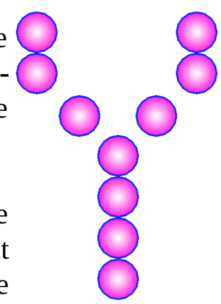
Details of Technology

? explain the process of sampling voltage.

? describe the advantages and disadvantages of digital recordings.

? create flowcharts for making a series of decisions.

? give examples of positive and negative feedback.



Look at the Sunday Comics with a magnifying glass and you might be surprised to see that all the patches of color in the pictures are really just clusters of dots. Look at a page printed by a dot-matrix printer, and you'll find the same thing about the lines in the letters--they're really just dots.

This is known as digitization. Something that flows smoothly in nature is broken into little pieces by technology. If the pieces are small enough, it would be hard to realize that they really were pieces at all. In fact, a cup of pure water is really made up of molecules of H_2O, but the molecules are so small that we can't detect them individually without special equipment.

Photographs are even grainy, because the colors you see are caused by individual specks of chemicals. This effect is probably easiest to see on big screen televisions. No matter how big the screen, American television is made of a screen of dots 640 by 480, with new dots flashed on-screen 60 times every second. Old computer games have very artificial graphics for this reason, and new systems are not only faster, but also show pictures made of smaller dots.

Although graininess is a disadvantage for digital images, it is also an advantage. If a picture is just a series of dots on a predictable grid, it could be copied exactly. Forgery of money is difficult because the forger must make the lines curve at just the right angle and be just the right thickness. If bills were originally digital, you could forge them by copying each dot and when you were done, there would be no difference between the

original and the copy.

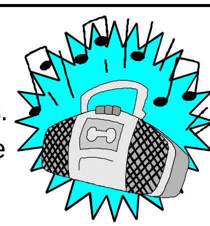
Real pictures fade and are hard to edit. Digital pictures don't fade, and if you want to edit them, you can just add or subtract dots. With the spread of computers and electronics devices, converting information to digits is a big business.

Signal and Noise

Throughout our discussion of information, we have used the word "signal" without ever mentioning its counterpart, noise. To understand information, you must be able to separate out the signal from the noise. Sometimes this is not so easy. When people listened to records, the sound of the needle scraping against the record sometimes made scratching and popping noises. Listeners took it for granted that this noise was not part of the information stored by the musician, but a limitation of their equipment. Likewise with magnetic tapes, a background "hiss" was a normal part of the sound. Again, listeners assumed that the hiss was not part of the signal.

Some musicians did want these noises to be part of their experience. Especially as people stopped listening to records, some musicians added record noises to their original tracks, to give it an old-fashioned feel. Most often, though, the popping and hissing was something to be avoided. The Dolby noise reduction system was developed to get rid of the hissing sound that came from magnetic tapes. Unfortunately, it sometimes got rid of some of the signal, too.

POP QUIZ: What is the difference between signal and noise?



ANSWER: That's a good question! Both of them are caused by vibrations. Since all the vibrations overlap in a recording, it is hard to sort out the noise from the signal.

In some ways, the problem got worse as music studios got more sophisticated. Elvis Presley recorded his original hits with all of the band playing together, and being recorded onto one tape. Twenty years later, it was rare to record an album "live" like this. Bands would usually record each part separately and then mix them together. That way, you wouldn't have to worry as much about whether the microphone was too close to the drummer. You could just reduce the volume of the drummer's tape when you mixed it. This meant that there was a tape of the drummer (which hissed) and a tape of the band mixed together (which recorded the original hiss and added some of its own). That master tape was copied several times (with each taping adding more hiss) and these tapes were used to produce more tapes for consumers (which had even more hiss on them).

Analogue Signal

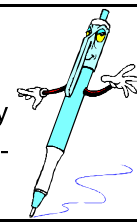
Audio engineers dreamed of a system that would eliminate everything except the original signal, even on the consumer's copy of the original. The way this happened was with digital technology. If you were asked to draw a wave just like the one below five times, each time you copied it would probably be slightly different than the first. If you were asked

to copy the series of numbers at the margin five times, you should be able to make each copy exactly the same as the first. That's the trick to digitizing information. A sound (or picture) with wavy lines has to be converted into a series of exact numbers, so it can be copied exactly.

1 5 3 7 2

Digital Signal

POP QUIZ: Why is a script signature harder to forge than printed writing?



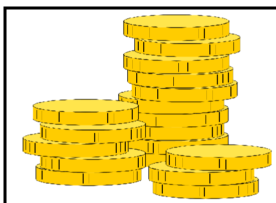
ANSWER: Curves are hard to duplicate exactly, since they have so many joints they can move. Even so, some people (like the President of the United States) have a machine that mimics the curves they use when they sign their name.

Digitizing Numbers

The name "digital" comes from the Latin word for finger. When you count on your fingers, you count with whole numbers. You can figure out fractions if you need to, but it's not easy to do with your fingers! We have developed a system of counting based on our number of fingers--ten. When we get to ten, we need a new place to keep track of bigger numbers. Instead of using your toes to help you count to twenty, you could use your toes to keep track of how many "tens" you've counted out. The toes tell you how many tens, and the fingers tell you how many ones. Write down the number of toes first, and then the number of fingers on its right, and you have a normal "two-digit number".

This works best because we have ten fingers. If we didn't have fingers at all, we might only count to two--left hand, right hand. Then we'd use our legs to tell us how many twos we've counted. It's a much slower process. Here is the reason for discussing it. When we use magnets, we don't have ten poles; we have two. When we talk about light, it is much easier to talk about whether it is on or off, rather than exactly how bright it is. When we talk about electric current, it is easier to tell whether it is on or off, rather than exactly how strong it is. For these reasons, a counting system based on two was invented. It is called binary code.

When money was based on gold and silver, a binary system was in place. Each coin was worth twice as much as the one before. For example, the penny was the smallest coin. Double a penny, and you have a two-pence (called a "tuppence" in Old England). Double that and you have a quid (worth four pennies). Double a quid and you have a shilling (worth eight pennies). Double a shilling and you have a pound (worth 16 pennies). The pattern could continue on as high as you like.



POP QUIZ: What would be the next two coins in the series: 1, 2, 4, 8, 16, ...?

ANSWER: Each coin is twice the value of the one before it, so the next coins would be worth 32 pennies, and 64 pennies.

This made it fairly easy to make exact change. You can try an exercise in class where you make exact change for any price at all, as long as you have one of each coin. For example, something worth five cents would need a penny and a quid. Something worth ten cents would need a shilling and a tuppence. Something worth eleven cents would need a shilling, a tuppence, and a pence. And so on. The chart shown tells how you would make exact change for all the numbers from 1 to 31. If there is a "1" in the column, you need to use that coin, but if there is a zero, you would not.

It would be possible for a store to put its price in this code, if it wanted to. Instead of marking a lollypop "15 cents", it could mark it "01111". That would mean that you don't need a pound, but you do need a shilling, a quid, a tuppence, and a pence to buy it. You have probably seen someone at a cash register bumbling about how to make the right change. The advantage of this binary system is that it would tell them exactly which coins to give out, so even a robot could do it. The disadvantage would be that something that cost $2.57 would need a tag big enough to hold the number "100000001". (That code has a 1 in the "256 column", and a 1 in the "1 column". Get it?)

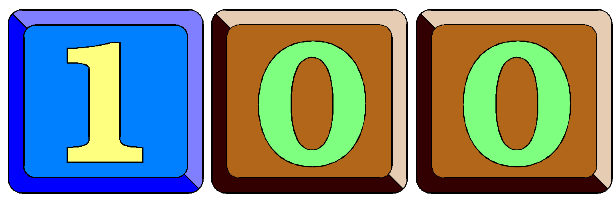
Value of column

16	**8**	**4**	**2**	**1**
0	1	1	1	1

= 15¢

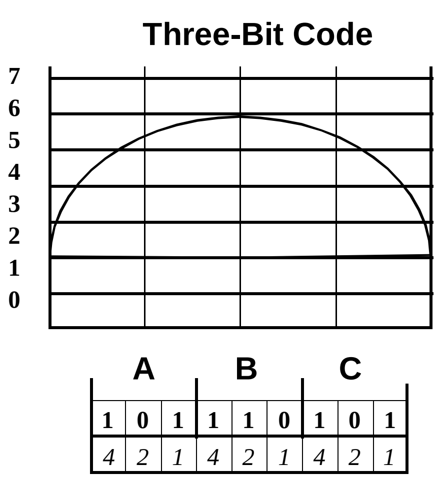
POP QUIZ: What is the binary code for the number 100? How about 4?

ANSWER: The code for 100 is "1100100" (64+32+4). The code for 4 is "100".



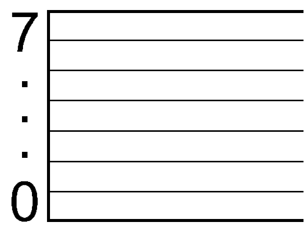
Digitizing Sound

We have already seen how sound can be stored as a wavy line. To digitize the sound, we need to be able to store it as a string of numbers. This is done by a process called sampling. The chart below shows how a hypothetical sound wave could be digitized. The chart has many vertical lines that cross the wave in only one place. Where it crosses is the exact location of the microphone when that sound was recorded. The chart also has seven horizontal lines that cut across the wave. These are called the sampling values, because when you convert the wave to numbers you have to round it off to one of these values. No fractions are allowed!



For example, the vertical line marked A crosses the wave in between the values of 5 and 6. We must give it an exact value, so we pick which value is closest. In this case, it is closer to 5. In the blocks below the line, we can fill in 101 (which is the binary code for 5). We do the same thing with each of the vertical lines until the whole wave

has been converted into numbers. These numbers can now be copied exactly, with the last copy just as good as the first! We have successfully digitized sound.



POP QUIZ: Why does a common digital scale go from 0 to 7, instead of 0-9?

ANSWER: A three-bit code can get you from 0 (000) to 7 (111). To go higher, you'd need a fourth bit, and then you may as well go from 0 to 15 (1111) instead of just 0 to 9 (1001)!

You probably noticed two problems with this process. First of all, we only sampled the wave every so often. In between the samples was a lot of detail that never got recorded. If you have ever heard a cheap synthesizer try to sound like a violin, you may have noticed that it sounded strange. If the original violin wasn't sampled often enough, that may be the reason. The other reason may be that the wave was rounded off too much. In our example, the real wave wasn't exactly 6, but we pretended that it was; that will distort the sound as well.

POP QUIZ: How many lines would you need to eliminate the need for rounding off?

ANSWER: Trick question! As long as you have a definite number of lines, you will always have values between them! That means that digitized sound will always be approximate, but the approximations can be better or worse depending on the number of lines.

The compact disk was the first audio technology to digitize sounds. In the first few years of its existence, there was a serious debate about whether the digitized sound distorted the original sound too much. The industry continued to sample more often (now 40,000 times per second) on a more detailed scale (now 64,000 horizontal lines), until experts agreed that they couldn't hear any distortion in the sound. You could continue to get more and more detail, but it would cost more money, and at a certain point, no one would hear any improvement.

The electronics industry has also introduced a digital audio tape (DAT). The difference between this tape and the old style of tape (called analogue) is simple. In the old style of tape, the magnetic signals gradually got stronger as the waveform rose and gradually got weaker as the waveform dipped. This gradual process tried to match the original signal, but in practice it couldn't. If you ever copied a tape over and over, you could easily hear the loss of signal. In DAT, the magnetic signals aren't designed to be strong or weak. They are just "there" or "not-there". On the tape, you have patches that get magnetized according to binary code. If the code is 11001, you get "magnet" "magnet" "no-magnet" "no-magnet" "magnet". The magnetized sections don't have to be magnetized to the same value as the original, because the value is irrelevant. As long the DAT player can tell whether the patch was magnetized, it can read the pattern as an exact value. Even if you made a copy of a copy of a copy, each

of these copies would sound as good as the first.

Some people in the music industry are very worried about this new technology. Now, they get money for every good copy of the music that goes out. Some people make copies for their friends (even though it is illegal!), but the copy of the copy is so bad that most people would rather buy the original. That way, the record company (and the musicians) make money. Since illegal copies made with DAT are just as good as the original, they worry that very few people will buy the original, and they will go out of business.

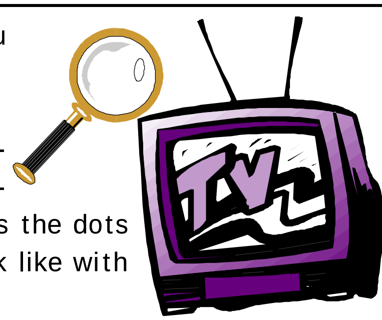
Compact disks give the same quality sound as DAT, but there is no way for consumers to record onto compact discs, so anyone who wants a good copy has to buy an original. This may not be the case for long, though. Some companies are developing the technology that would let consumers record their own compact discs.

Digitizing Pictures

Television used a form of digitization right from the start. In nature, we see scenes where the colors flow smoothly across the screen, and the images run smoothly through the scene. On TV we see a set of separate dots, 640 across by 480 down, and these dots are changed from one definite color to another, 60 times every second. It may look smooth, but you only need to look closely at the screen to see that it is not. Anyone who has worked with a computerized drawing program probably noticed this kind of distortion. If the dots aren't small enough, diagonal lines look jagged, and circles don't curve the way they should.

Older Americans who did not grow up with a TV in the house reported that they had a hard time seeing TV as more than a bunch of dots. A painter, named Georges Seurat, made some famous paintings this way in the 1880s. His paintings looked like regular landscapes from a distance, but were really made by individual dots. He even showed that our eyes can be tricked into seeing colors that aren't there. Some patches, that looked magenta from a distance, were just blue dots and red dots when observed up close.

POP QUIZ: If a character on TV was reading a book, and you zoomed in on it, what would you see?



ANSWER: If the words in the book looked blurry without magnification, they would still be blurry after you zoomed in. The image only has a certain number of dots, and zooming in only makes the dots bigger! Some computer programs try to guess what it would look like with more detail, but the results are only probabilities!

This ability to trick the eye is especially important for our study of television, because it does that, too. You can see a wide variety of colors on TV shows, but sending a TV signal with so many different colors would be very difficult. Instead, the TV signal sends shades of three colors: red, green, and blue. Computer monitors, close relatives to television sets, are sometimes labeled RGB for these three colors. When you mix these

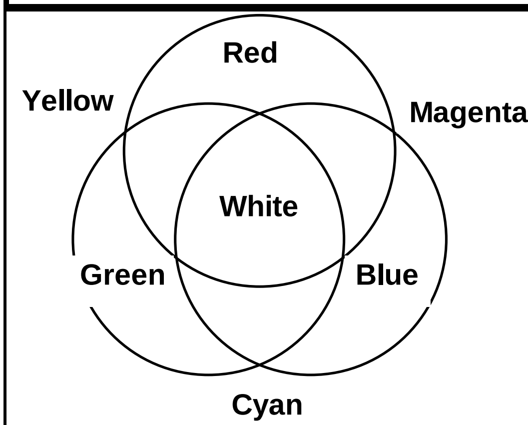
three colors together on the TV screen, you can get tremendous variety.

If you have ever mixed paints together in an art class, you may have some insight into the possibilities. Paints, however, are not the same as the light coming from a TV set. Paints include chemicals that reflect only certain colors of the rainbow. In normal lighting, all the colors of the rainbow (ROY G BIV, for Red, Orange, Yellow, Green, Blue, Indigo, Violet) shine on things. A green paint will absorb the ROY and the BIV and reflect the green. Since green gets in your eyes, you call the paint green. In fact, green is the color that green paint rejects! If you don't shine any green light on the paint, it will have nothing to reflect and will look black (or at least gray). Also, if you mix other colored paint with green, both paints will absorb light, and the mixture will usually be darker than before.

POP QUIZ: What would a yellow shirt look like if it was illuminated with a red light?

ANSWER: If it was a pure yellow it would appear black, but yellow is often a mixture of red and green. Therefore, the shirt would reflect the red light, and appear red.

Mixing Colored Light

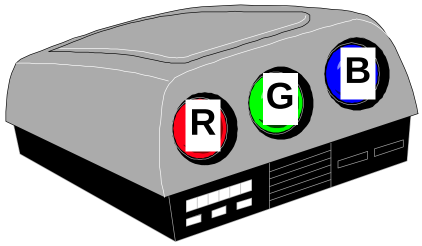


With a television set, you don't need to shine light on it, because it produces its own light. When green is the only light produced, the screen obviously will look green. How about when green and blue lights both hit the same part of the screen? If you mixed blue and green paint, you would get a darker color that you might call aqua. With blue and green light, you get a brighter color that scientists call cyan (basically a bright aqua!). That pattern will help you remember the other combinations: mixing paint colors makes a darker shade, mixing colored light makes a brighter shade.

Mixing red and blue paints will produce a darker shade of purple. Red and blue lights will produce a brighter shade of purple, called magenta. Mixing red and green paints will produce a darker shade of brown. Red and green lights will produce a brighter shad of brown called (this may surprise you!) yellow. If you mix red, green, and blue paints, you will probably get a shade so dark you'd call it black. We call objects black when they absorb all the light you shine on them, and no light comes back to your eyes. The red paint will absorb the GBIV; the green paint will absorb the ROY BIV; the blue paint will absorb the ROY G. Is there any color of the rainbow that didn't get absorbed by this mixture? No!

When the TV screen has red, green, and blue light shining from it, you get an abbreviated form of the rainbow. You're missing the Orange, Yellow, Indigo and Violet, but your brain doesn't really notice the difference, unless there's something to compare it

to. If you want the TV screen to appear black, you can easily do that by turning off all of the three colors. When no light comes from an object, it looks black!



POP QUIZ: What would a projection-TV picture look like if the blue light was blocked?

ANSWER: Even without the blue light, the reds, greens, yellows, browns and blacks would be unaffected. However, something that should appear white (RGB) would appear yellow (RG). Other mixtures also be yellowish or brownish.

You might ask some reasonable questions, like "what about orange?" It would help if you could experiment with a computer paint program at home or at your school. Some of these programs let you adjust the palette of colors, and you can see all of the possibilities. This brings up the second way that pictures can be digitized, other than breaking it up into individual frames and breaking the frame into tiny dots.

When you mix red, green, and blue light, you can control how much of each color you want. You can do this in a non-digital way (like television broadcasts do, or in a digital way (like computers do). The non-digital way (called analogue) allows you to adjust the intensity of each color on a continuous scale. However strong the green signal is, your TV and your VCR try to match that strength as well as it can. When you copy that signal over and over, the strength of the signal can change each time, depending on the quality of your equipment.

The digital way, which you could see on a computer paint program, is like a ladder. You can only stop on the steps, not in between. This limits your possibilities, but it makes sure that every time you send or copy the signal, you'll get the same thing. Some paint programs allow you to choose from 256 levels of intensity, and when everything is mixed, your eye will never notice the missing possibilities! Computer fans will be able to tell you about EGA, VGA, and SVGA. These names just tell you how good the digital system is. As computer display systems go up in price, the dots get smaller and the shades of color get more realistic.

The same process is beginning with broadcast television. High-density TV (HDTV) would allow more dots on the screen to make it look better. At the same time, the TV industry decided to make these screens a little wider than the current ones. If you are a movie fan, you may have heard of the aspect ratio of film and TV. That is a fancy term for a simple fact: movie screens are much wider than TV screens. Most movies that get shown on TV have their edges chopped off because they won't fit! They call it "letterboxing" when they show the movie from extreme-left to extreme-right, but that leaves part of the TV screen on the top and bottom with no picture. When HDTV becomes the industry standard, all the old shows will have strips on the left and right with no picture, because the old TV shows were made for a narrower screen!

Digitizing Decisions

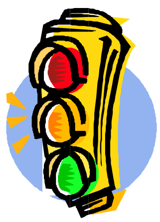
In order to prepare ourselves for the chapter on computer technology, we need to look at another kind of digitization. Like our code for numbers, the system for answering questions is also binary. The only two options available are 0 and 1, where "0" means "no" and "1" means "yes". This simplifies things for the computer, because there is no ambiguity. It is told exactly what conditions it is dealing with. But there are drawbacks to it as well.

With this kind of system, only certain questions are possible. You can't answer the question, "what color is the book?" with a yes or no! This means that you need to break down that one question into a series of questions to nail down the answer. "Is the book red? Is it green? Is it blue?" and so on.

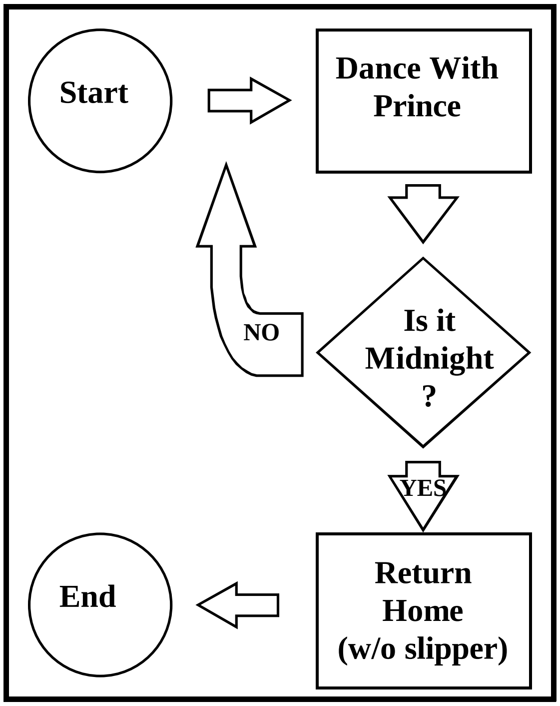
Even then, the yes-no limitation makes things difficult. It is not always easy to give a clear yes-or-no answer. If the book is cyan, for example, how do you answer the questions? Is it blue? Well, yes, but it is green also... You can see that there is a real art to asking only yes-no questions that really give the information that is needed.

POP QUIZ: The question "What color is the traffic light?" has three possible answers. How could you reword the question for a computer program?

ANSWER: You'd have to ask thee separate questions: "Is it red?", "Is it yellow?", "Is it green?".



The ability to ask the right questions can let computers help you deal with complex issues. Cinderella's night at the ball may not have been that complex, but it helps illustrate the point. She was told by her fairy godmother to return home before midnight NO MATTER WHAT! Naturally, she was so excited about the ball and meeting her prince that she had a hard time keeping track of the time. If she had been able to use a digital watch with an alarm, she would have been able to enjoy the evening without a care. When she programmed the watch to ring at, say 11:58 p.m., what she really was doing was giving a machine something extremely simple to "think" about. The watch's memory would be programmed to ask the same question over and over: "Is it 11:58 p.m.?" As long as the answer was "no", then it would simply ask the question again and again. When it finally got "yes" as an answer, that "yes" would have been a digital "1"

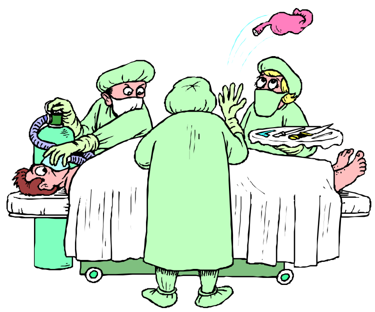


which would have sent a burst of current to the alarm. All of the "no" answers were digital "0"s and no current would have been sent to the alarm.

This thinking process is easier for most people to follow if it is put into a kind of road-map that shows every step. In the computer industry it is called flow-charting, and it is at the foundation of every computer program that is developed. The program almost always has a definite beginning and end, and these are drawn as circles labeled "Start" and "End". Any yes-no questions go into a diamond shape, with one arrow showing where to go if the answer is yes and another showing where to go if the answer is no. Any actions that need to be taken (like ringing the alarm) are placed in a rectangular box. Cinderella's program for her digital watch is shown on the previous page.

POP QUIZ: Is it possible to program a computer to go through all of the thinking processes that a surgeon goes through during an operation?

ANSWER: That's a good question! It's one thing to have a robot that moves where you tell it to; it's another thing to put the robot on autopilot! We may find that even the best computer programs of the future can't match the insight of a person, but who knows?



Some people dream of a complex computer program that could "think" like experts. For example, medical programs could be developed that would duplicate the judgement of the best experts in each field. These programs are commonly called "expert systems". The challenge in creating an expert system is trying to figure out the thought processes of an expert. That would include every question they might ask, every observation they might make, every possible diagnosis they might make, and every kind of treatment they might prescribe.

Beginning expert systems are already in use. However, there are still serious doubts about whether the systems are really as good as the experts. One limitation of expert systems is that they can only do what the programmer told them to do. The real expert may rely on hunches, or have a sudden insight that would lead them in a different direction. To develop a good expert system, all of these hunches and insights have to be spelled out ahead of time.

On the other hand, many jobs can be done by following the same patterns over and over. In manufacturing plants, robots have been programmed to perform repetitive tasks that used to be performed by people. Some people argue that we should not let people's jobs be performed by machines. Others argue that we can give the repetitive, back-breaking jobs to machines and save the creative jobs for people. One thing that cannot be denied is that jobs where people do repetitive tasks are being phased out, and many of the remaining jobs emphasize problem-solving and trouble-shooting. Robots don't seem likely to replace us in jobs that require creative thinking.

Still, some computer experts believe that the day will come when you can have a conversation on the Internet and not be sure whether you are talking with a computer or a person. Science fiction stories commonly have robots or computers that seem quite human, except for their hardware.

Concept Summary

Information can be coded using analogue or digital systems.

? In an analogue system, the information is stored in a smooth, continuous pattern that mirrors the source of the information.
? In a digital system, the information is sampled every so often, assigned a number, and stored as a series of digits.
? Analogue systems are susceptible to noise. The "mirror" contains defects that muddle the output. Digital systems overcome this problem by storing the information as a series of exact numbers.
? Digital systems are susceptible to roughness. If the information is not sampled often enough, or if the steps on the number scale are too large, the details of the original information will be lost.

Sounds can be reproduced by vibrating a speaker in the same patterns that the microphone was vibrated.

? In an analogue system, the strength of the input voltage makes a smooth, continuous change in the output voltage.
? Sounds can be digitized by measuring the input voltage at regular intervals, rounding off each value, and saving it as an exact number.
? The realism of the sound depends on how often the sound is sampled and how much "rounding off" the scale requires.

Images can be recorded by detecting the color and intensity of light in the original image.

? If light from the image is focused on certain chemical-coated paper, it makes a chemical change that matches the color and intensity of the original light.
? Most of the light from the images can be filtered into red, green, and blue components. By recording the intensity of each of these three components, a wide variety of colors can be produced that imitate the original image.

Text can be recorded graphically or digitally.

? Digital recording of text, like computer file storage, assign a code to each character of the alphabet and store that code.
? Graphic recording of text, like fax machines and optical text scanners store an image of the text dot by dot.

Thought processes can be coded digitally by finding a series of questions that allow only "yes" or "no" answers, and encompass everything that is important about that topic.

? These questions can only have yes or no answers; if "maybe" is a possible answer, the question needs to be rewritten.
? A "yes" answer is coded with a "1", a "no" answer with a "0".

Review Questions

1. What kind of noise do you get with phonograph recordings?
2. What kind of noise do you get with magnetic tape recordings?
3. What system was developed to eliminate tape hiss?
4. Why does mixing tapes produce more noise?
5. Why are magnets perfect for a binary system of counting?
6. Why is light perfect for a binary system of counting?
7. Can a binary code represent any number?
8. What would be one advantage of a binary money system in making change?
9. What is sampling? What is one disadvantage of sampling?
10. How can "sampling" errors be minimized?
11. How can "rounding off' errors be minimized?
12. How many times each second do compact disks sample sound waves?
13. How many values are on the scale used to round off sound waves?
14. How did analogue systems try to match the original sound wave?
15. How many dots are there on a TV screen?
16. How frequently are these dots changed?
17. What three colors are used in TV sets?
18. Why do mixed paints look darker than the originals?
19. Why do mixed lights look brighter than the originals?
20. What makes our current TV system analogue?
21. What two things will HDTV do to the TV picture?
22. What kind of questions can be programmed into a computer?
23. What is an expert system?